DRY ICE FEEDING APPARATUS AND METHOD

This application claims the benefit of U.S. provisional application Serial No. 60/509,875, filed October 9, 2003.

Background of the Invention

This invention relates to the field of dry-ice blast cleaning systems. More particularly, this invention relates to an apparatus and method for feeding dry ice to a blast cleaning system under optimized conditions irrespective of the ambient atmospheric conditions.

The use of dry ice for blast cleaning is well known in the art. Examples of conventional blast-cleaning systems are described in U.S. Patent No. 4,389,820 and U.S. Patent No. 5,365,699, which are incorporated herein by reference.

In such systems, pieces of dry ice (solidified CO_2) are drawn into a fluid stream (typically compressed air) in a blast gun by the action of a venturi, where they are entrained into the fluid stream and propelled out of the gun to impinge against the surface to be cleaned. After the pieces collide with the surface, removing unwanted surface coverings by their impact, they sublimate into gaseous CO_2 and become part of the ambient atmosphere. The only residue from this process is the removed surface covering.

The sizing of the dry ice being used for cleaning varies with the method used to produce the pieces and the items being cleaned. One of the most common sizes approximates the size of rice grains (typically about 0.100 to 0.150 inch in diameter and 0.125 to 0.25 inch in length). One example of where rice-sized dry ice is used is for cleaning printing presses.

Rice-sized dry ice pieces typically are produced by machines called pelletizers. Conventional examples of these machines are disclosed in U.S. Patent No. 4,780,119 and U.S. Patent No. 5,475,981, which are incorporated herein by reference. In these machines, liquid CO_2 is injected into a cylinder, where it solidifies in the form of snow-like solid CO_2 particles. A piston within the cylinder then compresses the solidified CO_2 and extrudes small-diameter dry ice segments through orifices in a die at one end of the cylinder. These dry ice segments are either sliced during extrusion or further broken down to form rice-sized pellets.

Another known method to obtain dry ice pieces for cleaning is to shave pieces from a block of dry ice (typically weighing about 50 lb.). The shaved dry ice typically varies widely in size, with some large pieces 1/8 inch to 3/16 inch in diameter and some smaller pieces the size of talc particles. An example where shaved dry ice is used is for cleaning molds.

A third known method for obtaining dry ice pieces is to take rice-sized dry ice pellets and grind them to a controlled particle size of less than 1 millimeter. An apparatus and method for producing such particles is disclosed in U.S. Patent No. 6,174,225, which is incorporated herein by reference. An example of an application for the controlled-particle-size system would be for cleaning delicate items such as printed circuit boards.

There are different advantages and disadvantages to using the three methods for producing dry ice particles mentioned above. For example, rice-sized material usually is available only in large cities. The blocks for shaved dry ice are more widely available, but the shaving process results in particles that vary widely in size. In addition, the blocks from which dry ice pieces are shaved normally include glycol as a binding agent to prevent the block from falling apart, and many companies prefer

not to introduce chemicals such as glycol into their environments. Moreover, handling large blocks of dry ice presents unwanted safety hazards. Furthermore, both shaved and rice-sized material can damage delicate substrates, which typically require controlled-sized dry ice particles. Current methods for producing controlled-sized particles, however, require rice-sized pellets as the source material.

Another form of dry ice material is the rod-shaped dry ice nugget, which typically is 1/4 inch to 3/4 inch in diameter and ½ inch to 8 inches long. The use of nuggets would be advantageous because they are available much more commonly throughout the world than rice-sized pellets and cost much less than rice-sized pellets. Nuggets also have a much longer shelf life than the smaller-sized forms of dry ice currently available in the market. The problem presented by the use of nuggets is that their size needs to be reduced dramatically for use in dry ice blast cleaning.

Another problem with conventional dry ice blasting systems is that they are affected by ambient atmospheric conditions. In particular, operation can be difficult in areas of high humidity. In such conditions, the dry ice particles cause moisture in the air to condense around the particles as liquid water and/or water ice, which in turn causes the dry ice particles to adhere to one another and clog the system.

Summary of the Invention

The present invention addresses the problems of prior art dry ice blasting systems by providing a dry ice feeding apparatus that includes a sealable dry ice hopper that can be pressurized with a pressurized gaseous fluid such as compressed air, particularly the same supply of compressed air that powers the blasting system.

As embodied and broadly described herein, the dry ice feeding apparatus of this invention comprises a hopper adapted to store a supply of dry ice pieces and

having an upper opening and a lower opening; a lid adapted to cover the upper opening of the hopper and including a seal member providing a fluid seal between the lid and the upper opening of the hopper; and a mixing chamber disposed beneath the lower opening of the hopper. The mixing chamber includes a mixing cavity, a dry ice inlet in fluid communication with the mixing cavity and the lower opening of the hopper and adapted to permit dry ice pieces to be supplied from the hopper to the mixing cavity, a fluid inlet adapted to connect a supply of pressurized gaseous fluid to the mixing cavity, and a fluid outlet adapted to connect the mixing cavity to a blast gun or other dispensing device. The mixing chamber directs flow of the pressurized gaseous fluid from the fluid inlet through the mixing cavity and out the fluid outlet and permits dry ice pieces supplied from the hopper to the mixing cavity to become entrained in the gaseous fluid flowing through the mixing cavity and out the fluid outlet. The dry ice inlet of the mixing chamber further provides a fluid connection between the fluid inlet of the mixing chamber and the hopper to permit the gaseous fluid to pressurize the hopper when the lid seals the upper opening of the hopper.

In a more specific embodiment, the gaseous fluid is compressed air and the hopper includes a substantially cylindrical upper portion, a frusto-conical lower portion depending downwardly from the upper portion of the hopper, and a head portion disposed atop the upper portion of the hopper. The upper opening of the hopper is in the head portion and provides access for loading dry ice pellets into the hopper. The lower opening of the hopper is at the bottom of the lower portion.

Furthermore, the invention includes a method of feeding dry ice pieces to a blast gun or other dispensing device, comprising the steps of providing a supply of dry ice pieces in a sealable pressure chamber having an opening in its bottom for the exit of dry ice pieces from the pressure chamber due to gravity; providing a supply of

clean, dry compressed air to a mixing chamber that is in flow communication with the opening in the bottom of the pressure chamber, the mixing chamber having an outlet connected to the blast gun or other dispensing device; allowing the clean, dry compressed air supplied to the mixing chamber to pressurize the pressure chamber; and directing a flow of the clean, dry compressed air across the mixing chamber and out of the outlet, whereby dry ice pieces exiting the opening in the bottom of the pressure vessel become entrained in the compressed air flow through the mixing chamber and exit the mixing chamber through the outlet to the blast gun or other dispensing device.

The accompanying drawings, which are incorporated in and which constitute a part of this specification, illustrate at least one embodiment of the invention and, together with the description, explain the principles of the invention.

Brief Description of the Drawings

FIG. 1 is a schematic elevational view of a dry ice feeding apparatus in accordance with the present invention;

FIG. 2 is a top plan view of the hopper lid for the present invention;

FIG. 3 is a partial sectional view of the hopper showing the hopper lid positioned in the hopper opening before closing;

FIG. 4 is an elevated view showing the hopper lid in its closed and sealed position;

FIGS. 5A and 5B are a schematic sectional view of a metering valve used in accordance with one embodiment of the present invention; and

FIGS. 6A and 6B are elevational and plan views of a crushing device used in accordance with another embodiment of the present invention.

Description of the Invention

Reference now will be made in detail to presently preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

The apparatus and method described below allow one to employ commonly available rod-shaped dry ice nuggets as the source of solid CO_2 material for blast cleaning, irrespective of the desired ultimate size of the dry ice pieces equivalent. The apparatus and method also provide a system that is effectively isolated from ambient atmospheric conditions, thereby eliminating clogging problems due to high humidity. These results are obtainable by utilizing a pressurized hopper that is in fluid communication with a crushing device.

An embodiment of the pressurized hopper is designated by reference numeral **10** in Fig. 1. Hopper **10** comprises a welded stainless steel pressure vessel. In the embodiment shown in Fig. 1, hopper **10** is intended to be mounted on a wheeled frame (not shown) for mobility and has an enclosed volume of approximately 16 gallons. It includes a cylindrical upper portion **12** that, in the disclosed embodiment, is approximately 18 inches in diameter and 12 inches high and is formed from 10-gage 304 stainless steel. Depending from the lower end of cylindrical upper portion **12** is a frusto-conical lower portion **14**. In the disclosed embodiment, lower portion **14** of hopper **10** is about 20 inches high. Changing the capacity of the hopper can be accomplished by increasing or decreasing the height of cylindrical upper portion **12.**

In the disclosed embodiment of hopper **10,** lower portion **14** is formed from the same material as cylindrical upper portion **12** and is welded to the upper portion. The included interior angle of lower portion **14** shown in Fig. 1 is about 40°, which ensures that the angle of the side wall is at least 65° from the horizontal and therefore

exceeds the typical angle of repose of dry ice particles. The open bottom end of frusto-conical lower portion **14** of hopper **10** in the disclosed embodiment has a diameter of approximately 4 inches and is connected, for example by welding, to a flange **16** having a circular opening about 4 inches in diameter. In the disclosed embodiment, flange **16** is stainless steel with a thickness of about 1 inch. The open bottom end of lower portion **14** and the opening of flange **16** define a lower opening **17** through which dry ice pieces exit hopper **10.**

The top of hopper **10** shown in Fig. 1 comprises a head portion **18** with an opening through which dry ice is fed into the hopper. In the disclosed embodiment, head portion **18** is formed from 11-gage 304 stainless steel and is shaped to coincide with a section of a sphere having a radius of about 18 inches. Head portion **18** is welded to the top end of cylindrical upper portion **12**. The opening **20** in head portion **12** (see Fig. 3) is slightly oval in shape and has an upstanding lip **22** with a horizontal flange **24**. The opening is covered and the hopper sealed by a complementary-shaped oval lid **26**. Lid **26** has a flange **28** along its periphery that carries an O-ring **30** on its upper surface and a formed-wire handle **32** pivotally connected to support members **34** attached to the top of the lid. To close the hopper opening and seal the chamber, lid **26** first is inserted through opening **20** into the interior of hopper **10** with the major axis of the oval lid orthogonal to the major axis of the oval opening. The lid then is rotated 90° while disposed inside the hopper so that the O-ring **30** on flange **28** coincides with flange **24** on lip **22** of the hopper opening **20** (see Fig. 3). The operator then raises the lid to provide contact between the O-ring on the lid and the lip flange and pivots the wire handle to lock the lid in place and seal the hopper (see Fig. 4).

As seen in Figs. 2-4, the lid handle has two relatively short ends **36** adjacent the handle's pivotal attachment to the lid. Fig. 3 shows the handle pivoted toward one

extreme while suspending the lid within the hopper. In Fig. 4, the handle is pivoted counterclockwise to its other extreme, which secures the lid in place. As will be understood by one of ordinary skill in the art, if the lid is positioned within the oval opening of the hopper with the O-ring contacting the lip flange of the opening, pivoting the handle from the position of Fig. 3 to that of Fig. 4 causes the handle's ends to rotate toward and into contact with the head portion of the hopper, resulting in the lid being lifted vertically upward and compressing the O-ring. When the handle's ends **36** are vertical, the O-ring is compressed to its greatest extent. Locking is accomplished by pivoting the handle to the position shown in Fig. 4. In this position, the handle cannot be pivoted further in the locking direction, as the middle portion **38** of handle **32** would be in contact with the surface of head portion **18** of hopper **10**. The handle also resists pivoting in a reverse direction because the handle's ends have been moved slightly beyond vertical, and the O-ring must be compressed in order to pivot the handle back toward its unlocked position. In addition, when hopper **10** is pressurized as discussed below, the pressure within the hopper also acts to push lid **26** upwardly, enhancing the seal.

In the embodiment shown in Fig. 1, the hopper also includes a vibrator **40** disposed on the hopper's lower portion **14**. The purpose of vibrator **40** is to eliminate "bridging" of the nuggets in the lower portion of the hopper as the diameter of the hopper decreases and maintain reliable downward movement of the nuggets within the hopper.

The source of compressed air for pressurizing hopper **10** can be the same air source used to feed the dry ice to the blast gun. The method of connecting this air source to the hopper will be explained with reference to Fig. 5A, which shows a metering valve **50** having an upper flange **52** and a lower flange **54**. Upper flange **52**

is connected to the flange **16** at the bottom of hopper **10**. This particular metering valve is used when the hopper is filled with rice-sized dry ice. As shown in Figs. 5A and 5B, metering valve **50** comprises a vaned rotor **56** that rotates within a housing **58**. Dry ice particles from the hopper enter the upper end of the valve's housing through a circular opening communicating with flange **16**. Once in the valve housing, the movement of the dry ice is controlled by the rotation of vaned rotor **58**, which can be driven by an air motor powered by the same compressed air that pressurizes hopper **10**. In the disclosed embodiment, the rotor has sixteen vanes **60**, all but one of which has a radial dimension that provides a clearance of about 0.08 inch with the arcuate side walls of the valve's housing. By providing this clearance, vanes **60** operate to feed the rice-sized dry ice particles from the top of the valve to the bottom of the valve without crushing the particles or further reducing their size. One of vanes **60** can have a smaller clearance with the side walls (about 0.005 inch) and serve to wipe the side walls clean as the rotor rotates.

With further reference to Fig. 5A, mounted at the bottom of metering valve **50** (e.g., via a flange **62** mating with flange **54**) is a mixing chamber **64**, which can be formed from a 4-inch diameter pipe cap. Mixing chamber **64** has an air inlet **66** and a diametrically opposed air/ice outlet **68**, both in flow communication with mixing cavity **70**. The open upper end of mixing chamber **64** defines a dry ice inlet **71** connected to lower opening **17** of hopper **10** to permit dry ice pieces to be supplied from hopper **10** to mixing cavity **70**. Air inlet **66** is connected to a source of compressed air (e.g., the same source that pressurizes hopper **10**), and air/ice outlet **68** is connected to the blast gun or other dry ice dispensing device. In situations where the compressed air supply has a pressure of about 80 psi and a flow rate of about 150

cfm, the diameter of inlet **66** can be 1 inch and the diameter of outlet **68** 1½ inches, with outlet **68** having a downstream reduction to 1 inch.

The compressed air introduced to mixing cavity **70** serves both as the vehicle for delivering dry ice to the blast gun and as the means for pressurizing the hopper. As shown in Fig. 5, compressed air introduced to the mixing chamber flows upwardly through the metering valve into the sealed hopper. The compressed air also flows across mixing cavity **70** and out of outlet **68**, and the dry ice particles fed downwardly by the vanes of the metering valve become entrained in this flow and are carried to the blast gun. The feed rate for the rice-sized dry ice particles into the mixing chamber is determined by the rotational speed of the rotor. With the disclosed embodiment of the metering valve, the rotor is operated at a minimum speed of 25 RPM. Operating the rotor a lower speed might result in a pulsed supply of dry ice to the blast gun.

By connecting hopper **10** to a source of clean, dry compressed air, the nuggets in the hopper are isolated from the ambient atmosphere and its humidity. One possible source of clean, dry compressed air would be stationary shop air compressor equipped with both an aftercooler and a supplemental air-dryer, which serve to remove moisture from the compressed air flow. Another possible source is a portable air compressor, which typically does not include any air-drying accessories aside from an aftercooler. I have found, however, that using an additional filter with a pore size of about 3 microns serves to remove enough moisture from the compressed air flow to adequately isolate the hopper from the moisture in the ambient atmosphere.

A pressure regulator can be used to limit the pressure of the air within hopper **10**. In the disclosed embodiment, a pressure regulator **72** is connected to the hopper via a fitting located in the hopper's head portion adjacent the hopper's opening, as shown in Fig. 1. To ensure safe operation, pressure regulation limits the pressure

within the hopper to 125 psi or less. Additional pressure taps can be used to monitor the pressure within the hopper at various positions. The pressurized air in the hopper also enhances the seal between the lid and hopper opening, as the pressure tends to push upward on the lid and increase the compressive forces on the O-ring.

When dry ice nuggets are used instead of rice-sized particles, the metering valve shown in Fig. 5 can be replaced by a size-reducing device. One example of such a size-reducing device is a crushing device of the type typically used in pipeline systems to reduce the size of lumps in pumped liquid slurries or in pneumatically or gravity fed dry bulk materials. Figs. 6A and 6B show a top plan view and an elevational view of a crushing device **80**. The crushing device disclosed in Fig. 6 is the Model 4FS-04 in-line crusher sold by Atlantic Coast Crushers of Kenilworth, New Jersey and disclosed in U.S. Patent No. 6,024,310, which is incorporated herein by reference.

With continuing reference to Fig. 6A, crushing device **80** employs a series of stationary and rotating blades **82**, **84** that cut and crush material flowing through the device. The stationary blades **82** typically are mounted to the device's housing, with the rotating blades **84** being mounted on a shaft 86 that turns relative to the housing. Rotary blades **84** can have a concave leading edge to assist in retaining contact with the dry ice nuggets as the blades rotate. Shaft **86** can be is connected to an air motor, although an electric motor, hydraulic motor, or other rotating device also could be used. The crushing device also acts as a metering valve, with the feed rate of reduced-size dry ice particles being a function of the rotational speed of the rotating blades.

As the dry ice nuggets are fed through crushing device **80** by gravity, the interaction of rotating blades **84** and stationary blades **82** cuts and crushes the nuggets

so that the dry ice pieces are reduced to sizes conducive for blast cleaning before entering mixing cavity **70** of mixing chamber **64**. The extent of size reduction accomplished by the crushing device is controlled by the spacing between the stationary blades, which act as a sizing grid preventing dry ice pieces larger than the blade spacing from passing through the crushing device into the discharge member. In situations where the industry standard of 1/8 inch or smaller dry ice particle size is desired, the crushing device can provide spacing of 0.125 inch between adjacent stationary blades, with the rotating blades measuring 0.090 inch in width to provide a nominal clearance of 0.0175 inch between stationary and rotating blades. Of course, if smaller dry ice particles are desired, the spacing between stationary blades should be reduced. Conversely, if larger particles are desired, the stationary blade spacing should be increased.

The apparatus discussed above was described in the context of a single-hose blast-cleaning system, in which the compressed air and dry ice particles are mixed together at the dry ice supply and sent to one or more blast guns for acceleration. The concept of a pressurized hopper also can be used with a two-hose system.

In a two-hose dry ice blast-cleaning system, one hose connects a source of flowing compressed air to a primary air inlet of a blast gun, which directs the airflow through a venturi or converging/diverging orifice to produce a region of low pressure air flow downstream from the orifice. This low-pressure region is connected by a second hose to a supply of dry ice particles maintained at atmospheric pressure, typically an unsealed hopper. The dry ice particles are drawn from the supply hopper to the blast gun through the second hose by air flow created by the pressure differential between the hopper and the low pressure region in the blast gun, where

the dry ice is entrained in the primary air flow and exits the blast gun to the strike the work piece.

When a pressurized hopper is used with a two-hose system, the pressure within the sealed hopper can be maintained at a relatively low elevated pressure, typically measuring about 3 inches of water column above atmospheric pressure. This pressurized two-hose system also can be used with either the metering valve or crushing device described above, in addition to the controlled-particle-size system disclosed in U.S. Patent No. 6,174,225.

An important advantage resulting from pressurizing the dry ice hopper is reducing the exposure of the dry ice pieces to humidity in the ambient atmosphere. Conventional dry ice blast-cleaning systems are prone to frequent interruptions or prolonged shutdowns when water ice forms within the equipment, especially under conditions of high humidity in the ambient air. As the demand for twenty-four-hours-per-day blasting operations increases, such interruptions are increasingly unacceptable. The system of the present invention eliminates these problems by using compressed air that normally is available in industrial plants to pressurize the hopper. Conventional compressed air sources used in industrial plants, which typically supply air at about 80-100 psi, use a dryer to remove humidity from the air supply. By employing this supply of clean, dry air to pressurize the dry ice hopper, the system of this invention isolates the dry ice pieces from the ambient atmosphere's humidity, limits the introduction of unwanted water vapor into the system, and thereby prevents the formation of problematic water ice in the system. By using this same air supply at inlet **68** of mixing chamber **64**, particularly in a single hose system, the dry ice is isolated from ambient conditions until it exits the blast gun.

Isolation can be provided even when the blasting system in not in operation. Typically, operation of the blast gun opens normally-closed ball valves in the air supply line upstream of the mixing chamber and at the blast gun. Consequently, the air pressure in the hopper is maintained when the gun is off. To avoid maintaining high pressures in the hopper during prolonged idleness, such as during overnight periods, the hopper or feed line can be provided with a bleed valve that reduces the pressure in the hopper but maintains it at a minimum level. For example, the hopper pressure can be maintained at about 3 inches of water column above atmospheric pressure for a two-hose system and at typical plant line pressures of about 80 psi for a single hose system. The bleed valve can comprise a backpressure regulator that will vent any excess pressure that might build up, along with a pressure relief valve and a burst disc.

These advantages are enhanced by utilizing a crushing device to reduce dry ice nuggets to the desired size on demand, as the blasting operation takes place. As noted above, nugget-size dry ice has a longer shelf life than the smaller pieces produced by pelletizers or block-shaving techniques. The combination of pressurizing the hopper and using dry ice nuggets as the source material for blast cleaning provides a much more economical, reliable, and flexible blast-cleaning system.

It will be apparent to those skilled in the art that additional modifications and variations can be made in the disclosed dry-ice feeding system without departing from the scope of the invention. The invention in its broader aspects is, therefore, not limited to the specific details and illustrated examples shown and described. Accordingly, it is intended that the present invention cover such modifications and variations provided that they fall within the scope of the appended claims and their equivalents.